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Effects of edge-stiffened circular holes on the web crippling strength of cold-formed steel channel sections under one-flange loading conditions

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ABSTRACT

Cold-formed steel sections are often used as wall studs or floor joists and such sections often include web holes for ease of installation of services. The holes are normally punched or bored and are unstiffened; when the holes are near to points of concentrated load, web crippling can be the critical design consideration. Recently, a new generation of cold-formed steel channel sections with edge-stiffened circular holes has been developed, for which web crippling may not be so critical. In this paper, a combination of experimental investigation and non-linear elasto-plastic finite element analyses are used to investigate the effect of such edge-stiffened holes under the interior-one-flange (IOF) and end-one-flange (EOF) loading conditions; for comparison, sections without holes and with unstiffened holes are also considered. A total of 90 results comprising 36 tests and 54 finite element analysis results are presented. Owing to manufacturing constraints, in the test programme, the edge-stiffener length was fixed at 13 mm. Good agreement between the experimental and finite element results was obtained. For the case of the unstiffened hole, it is shown that the web crippling strength is reduced by up to 12% and 28% for the IOF and EOF loading conditions, respectively. However, with the edge-stiffened circular hole, the web crippling strength is only reduced by 3% for the IOF loading condition and there is no reduction in strength for the EOF loading condition. The finite element model was used for the purposes of a parametric study on the effects of different hole sizes, edge-stiffener length and distances of the web holes to the near edge of the bearing plate. The results indicate that with a suitable edge-stiffener length, the web crippling strength of cold-formed steel channel section with holes can be as high as the one without holes.

1. Introduction

Cold-formed steel sections are increasingly used in residential and commercial construction for both primary and secondary framing members. Such thin-walled sections are well-known to be susceptible to web crippling, particularly at points of concentrated load or reaction [1] (see Fig. 1). Furthermore, openings in the web are often used to allow ease of installation of electrical or plumbing services. Such openings, however, result in the sections being more susceptible to web crippling, particularly when concentrated loads are applied near to the openings.

Web holes in cold-formed steel sections are normally punched or bored and so are unstiffened (see Fig. 2(a)). Recently, Yu [2] described a study on a new generation of cold-formed steel channel sections having web holes that are edge-stiffened. Fig. 2(b) shows a photograph of a cold-formed steel channel section with an edge-stiffened circular holes [3]. As can be seen, the web holes are stiffened through a continuous edge stiffener/lip around the perimeter of the hole. The study by Yu [2], while limited to bending, indicates that edge-stiffened holes can significantly improve the strength of cold-formed steel channel sections.

This paper is concerned with the web crippling strength of cold-formed steel channel sections having edge-stiffened circular web holes. Fig. 3 shows the definition of symbols used in this paper. While no previous research has considered the web crippling strength of cold-formed steel channel sections with edge-stiffened circular web holes, previous work on web crippling has been reported by Uzzaman et al. [4–7] and Lian et al. [8–11], who proposed design recommendations in the form of web crippling strength reduction factor equations for channel-sections under the interior-one-flange (IOF) and end-one-flange (EOF) loading conditions. Yu and Davis [12], Sivakumaran and Zielonka [13],

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Nomenclature

A	Web holes ratio;
a	Diameter of circular web holes;
b_f	Overall flange width of section;
b_l	Overall lip width of section;
COV	Coefficient of variation;
D	Overall web depth of section;
E	Young's modulus of elasticity;
FEA	Finite element analysis;
h	Depth of the flat portion of web;
L	Length of the specimen;
N	Length of the bearing plate;
P	Experimental and finite element ultimate web crippling load per web;
P_{EXP}	Experimental ultimate web crippling load per web;
P_{FEA}	Web crippling strength per web predicted from finite element (FEA);
r_q	Inside corner radius between web and hole edge-stiffener;
r_i	Inside corner radius of section;
t	Thickness of section;
q	Length of web holes edge-stiffener;
Q	Web holes edge-stiffener length ratio;
x	Horizontal clear distance of the web holes to the near edge of the bearing plate;
X	Web holes distance ratio;
$\sigma_{0.2}$	Static 0.2% proof stress; and
σ_u	Static ultimate tensile strength

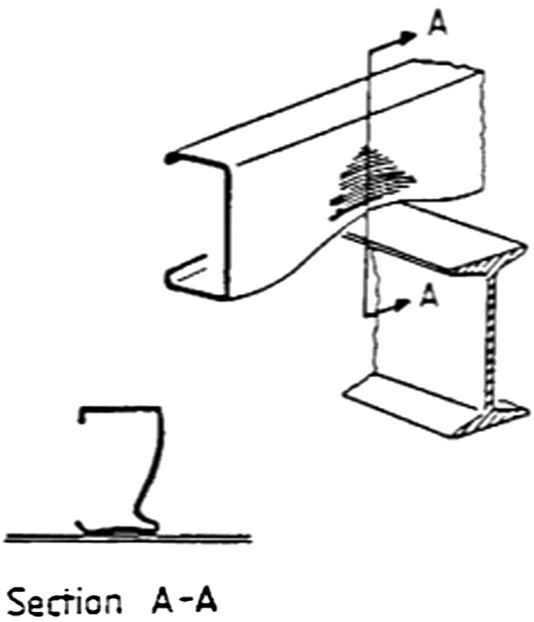
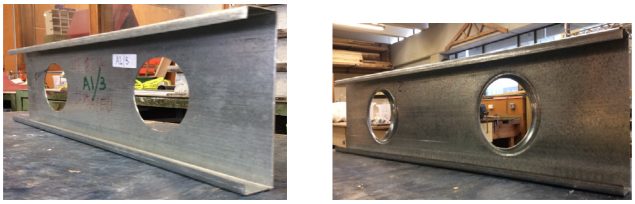


Fig. 1. Web crippling at a support point [1].



(a) Section with unstiffened holes (b) Section with edge-stiffened holes

Fig. 2. Cold-formed steel channel sections with web openings.

LaBoube et al. [14–15] and Chung [16–17] also reported research on the web crippling of channel section with unstiffened web openings. For aluminium sections, Zhou and Young [18] conducted a series of tests and numerical investigation on web crippling square hollow sections, again with unstiffened web holes. Yousefi et al. [19–22] proposed unified strength reduction factor equations for the web crippling strength of cold-formed stainless steel lipped channel-sections with circular web openings.

In this paper, a combination of experimental investigation and non-linear elasto-plastic finite element analyses (FEA) are used to investigate the effect of edge-stiffened circular web holes on the web crippling strength of lipped channel sections for the interior-one-flange (IOF) and end-one-flange (EOF) loading conditions, as shown in Figs. 4 and 5, respectively.

The general purpose finite element programme ABAQUS [23] was used for the numerical investigation. A good agreement between the experimental and finite element results was obtained. The finite element model was then used for the purposes of a parametric study of the effect of different web hole sizes, edge-stiffener length and position of holes in the web. The results indicate that the edge-stiffened circular holes can significantly improve the web crippling strength of cold-formed channel sections.

2. Experimental investigation

2.1. Test specimens

A test programme was conducted on lipped channel sections, as shown in Fig. 3 subjected to web crippling under EOF and IOF loading condition. Two depths of channel-sections were considered, namely the C240 and C290 channels having the nominal depth of 240 mm and 290 mm, respectively. All holes had a nominal diameter (a) of 140 mm and an edge-stiffener length (q) of 13 mm; the radius (r_q) between the web and edge-stiffener was 3 mm. The test specimens comprised two different section sizes, having nominal thicknesses (t) ranging from 2.0 mm to 2.5 mm; the nominal depth (d) of the webs ranged from 240 mm to 290 mm; the nominal flange width (b_f) for both sizes is 45 mm.

The test programme considered both webs having unstiffened circular holes and webs having edge-stiffened circular holes. Channel sections with no circular web holes (i.e. plain webs) were also tested, in order that the strength reduction can be determined experimentally.

The ratio of the diameter of the circular holes to the depth of the flat portion of the webs (a/h) were 0.6 and 0.5 for the C240 and C290 section, respectively. All test specimens were fabricated with the circular web holes located at the mid-depth of the webs and centred above the bearing plates, with a horizontal clear distance to the near edge of the bearing plates (x), as shown in Figs. 6 (a) and 7(a).

The specimen lengths (L) used were according to the North American Specification [24] and the AISI Specification [25]. Generally, the distance between bearing plates was set to be 1.5 times the overall depth of the web (d) rather than 1.5 times the depth of the